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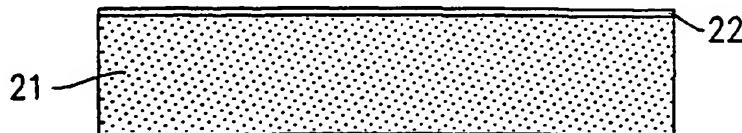
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### (54) Semiconductor substrate and method for fabricating the same

(57) A semiconductor substrate device comprises a first semiconductor substrate including a concave-convex surface and a second semiconductor substrate having an insulating film on a surface thereof. The first semiconductor substrate and the second semiconductor

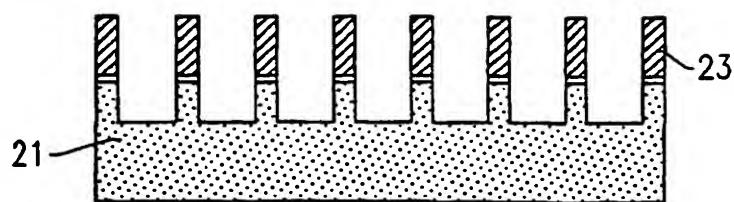
substrate are brought together so that the surface of the first semiconductor substrate and the insulating film provided on the surface of the second semiconductor substrate contact each other to form a cavity in the semiconductor substrate device.

*FIG. 1A*

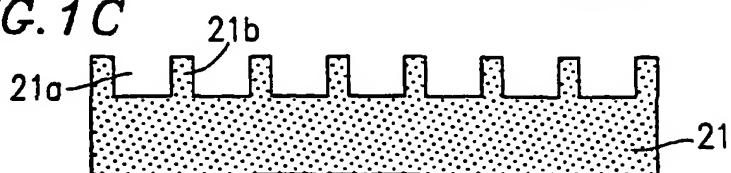


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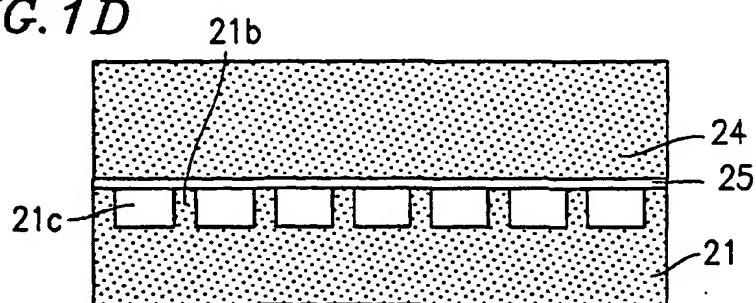
*FIG. 1B*



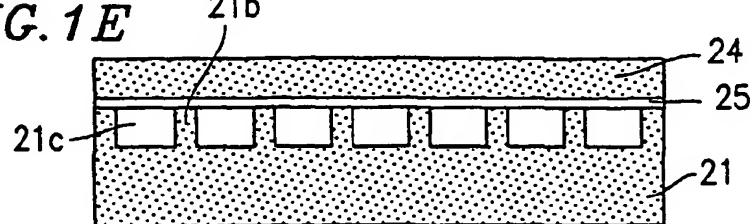
*FIG. 1C*



*FIG. 1D*



*FIG. 1E*



**Description****1. FIELD OF THE INVENTION:**

**[0001]** The present invention relates to a semiconductor substrate device in which a parasitic capacitance generated between the semiconductor substrate and circuit elements such as metal wiring, passive elements, active elements, and the like is reduced; and a method for fabricating the semiconductor substrate device.

**2. DESCRIPTION OF THE RELATED ART:**

**[0002]** In recent years, the market of mobile multimedia devices using radio communication, including portable information devices, such as digital cordless phones, e.g., digital mobile phones and PHS (personal handy-phone system) devices, has been expanded. In the research Institutes of manufacturers of mobile multimedia devices, colleges, and the like, techniques for improving high-frequency characteristics of a high-frequency device (e.g., a thin-film transistor) used in the mobile multimedia devices are being actively studied. One of the ways to improve the high-frequency characteristics is to reduce a parasitic capacitance generated between a semiconductor substrate, such as a silicon substrate, and circuit elements including wiring, such as metal wiring, and including elements, such as passive elements and active elements.

**[0003]** Methods for fabricating a semiconductor device in which the parasitic capacitance is reduced so as to improve the high-frequency characteristics are disclosed in, for example, Japanese Laid-Open Publication No. 03-196644 (hereinafter, referred to as "document 1") and IEEE TRANSACTIONS ON ELECTRON DEVICES, Vol. 45, No. 5, May 1998, pp. 1039-1045 (hereinafter, referred to as "document 2").

**[0004]** First, a method of document 1 will be described with reference to Figures 4A to 4D.

**[0005]** Figures 4A to 4D are cross-sectional views, each illustrating a step of a fabrication method of a semiconductor integrated circuit in which parasitic capacitance is reduced.

(1) As shown in Figure 4A, on a top surface of a semiconductor substrate 1 which includes a circuit element (not shown), a bonding pad 2 is provided in a predetermined position. The semiconductor substrate 1 is polished from a bottom surface to have a thickness of about 150  $\mu\text{m}$ .

(2) As shown in Figure 4B, photoresist layers 7 and 8 each having a thickness of 2 to 5  $\mu\text{m}$  are respectively formed on the entire top and bottom surfaces of the semiconductor substrate 1 covering the bonding pad 2. Then, an opening 8a is formed in the photoresist layer 8 on the bottom surface of the semiconductor substrate 1 in a position opposing

the bonding pad 2.

(3) As shown in Figure 4C, a cavity 3 is formed in a bottom portion of the semiconductor substrate 1 by isotropic wet etching using the photoresist layers 7 and 8 as masks. An etchant including sulfuric acid, hydrogen peroxide, and water at a ratio of 1 to 4:1:1 is used.

(4) As shown in Figure 4D, the photoresist layers 7 and 8 are removed. Thereafter, a silicon nitride film 6 is deposited on an inner surface of the cavity 3. Then, the resultant laminate is mounted on a metallized layer 5 of a ceramic package 4.

**[0006]** In the semiconductor integrated circuit fabricated by steps (1) to (4), the cavity 3 is formed in the bottom portion of the semiconductor substrate 1 in a position opposing the bonding pad 2. By providing the cavity 3 at this position, the parasitic capacitance generated between the semiconductor substrate 1 and the bonding pad 2 can be reduced.

**[0007]** Next, a method of document 2 will be described. Document 2 describes a method for fabricating a semiconductor device (e.g., a Silicon on Insulator (SOI) substrate device) in which parasitic capacitance generated between a substrate and a circuit element is reduced. An inductor of the semiconductor device, which is a passive element, is used in a high-frequency device along with the semiconductor device. The parasitic capacitance generated between the substrate and the inductor is reduced, and thus a quality factor of the inductor is improved. Therefore, high-frequency characteristics of the high-frequency device are improved.

**[0008]** Figures 5A to 5E are cross-sectional views, each illustrating a step of a fabrication method of the semiconductor device.

(1) As shown in Figure 5A, an insulating layer 11 having a thickness of 70 nm is laminated on an SOI substrate 10 having a thickness of 300 nm. Then, two gate oxide films 13 and an element isolation film 12 are formed on the insulating layer 11 by a LOCOS (Local Oxidation of Silicon) method. The two gate oxide films 13 straddle the element isolation film 12. A gate electrode 14 is formed on each of the gate oxide films 13.

(2) As shown in Figure 5B, tungsten (W) films 15 are grown on each of the gate electrodes 14, and on source and a drain regions formed on either side of each of the gate electrodes 14 by a selective CVD (Chemical Vapor Deposition) method. Thus, a plurality of elements 19 are formed.

(3) As shown in Figure 5C, on the tungsten films 15 above the source and drain regions, three-layer metal wiring is formed. Aluminum (Al) wiring 16,

forming an inductor, is formed on a top surface of the three-layer metal wiring. Then, a passivation process is performed. Thus, a circuit element is formed.

(4) As shown in Figure 5D, an opening 17 is provided by anisotropic etching. The opening 17 penetrates the laminate from the top surface of the three metal wiring to a top surface of the SOI substrate 10.

(5) As shown in Figure 5E, a cavity 18 having a depth of about 100 nm from the top surface of the SOI substrate 10 is formed. The cavity 18 is formed by isotropic etching in which sulfur fluoride (SF<sub>6</sub>) is injected through the opening 17. The cavity 18 extends under one of the elements 19 which is closest to the opening 17.

[0009] As a result of performing steps (1) to (5), semiconductor device is provided in which the parasitic capacitance generated between the SOI substrate 10 and the inductor 16 is reduced by providing the cavity 18. The semiconductor device having such a structure allows the inductor 16 to have improved high-frequency characteristics.

[0010] In the methods described in each of the documents 1 and 2, the parasitic capacitance generated between the substrate and the circuit elements can be reduced by forming a cavity having a low dielectric constant in the semiconductor substrate in a portion below the circuit elements (wiring, elements, and the like).

[0011] However, these methods have the following problems.

(1) It is required to form a cavity in a semiconductor substrate after the circuit elements and the like are formed on the semiconductor substrate to fabricate an LSI or the like. Accordingly, the number of steps of the fabrication method increases and the circuit elements formed on the substrate may be damaged when forming the cavity.

(2) Especially, in the method of document 2, it is required to reserve a region for forming an opening which penetrates a semiconductor substrate of a semiconductor device from a top surface having the circuit elements thereon. Thus, when the arrangement of multi-layer wiring becomes complicated and circuit elements are positioned close to each other, accurately forming an opening becomes difficult.

## SUMMARY OF THE INVENTION

[0012] According to one aspect of the invention, there is provided a semiconductor substrate device, comprising: a first semiconductor substrate including a concave-convex surface; and a second semiconductor substrate

having an insulating film on a surface thereof. The first semiconductor substrate and the second semiconductor substrate are brought together so that the surface of the first semiconductor substrate and the insulating film provided on the surface of the second semiconductor substrate contact each other to form a cavity in the semiconductor substrate device.

[0013] In one embodiment of the invention, the concave-convex surface of the first semiconductor substrate is defined by a plurality of convex portions formed at equal intervals.

[0014] According to another aspect of the invention, there is provided a method for fabricating a semiconductor substrate device, comprising the steps of: providing a resist layer having a predetermined pattern on a first insulating film on a first semiconductor substrate; performing isotropic or anisotropic etching of the first insulating film by using the resist layer as a mask, and performing anisotropic etching of the first semiconductor substrate by using the resist layer as a mask to form a concave-convex portion in a surface of the first semiconductor substrate to provide the first semiconductor substrate with the concave-convex surface; and removing the resist layer and the first insulating film, and then bringing the first semiconductor substrate and a second semiconductor substrate together so that the surface of the first semiconductor substrate and a second insulating film provided on a surface of the second semiconductor substrate contact each other.

[0015] In one embodiment of the invention, the method further comprises the step of thinning the second semiconductor substrate from a surface opposite to the surface thereof provided with the second insulating film after the step of bringing the first semiconductor substrate and the second semiconductor substrate together.

[0016] In one embodiment of the invention, the anisotropic etching of the first semiconductor substrate is performed by using KOH.

[0017] Thus, the invention described herein makes possible the advantages of providing a semiconductor substrate device which ensures the reduction of parasitic capacitance when elements are provided thereon, and a method for fabricating the semiconductor substrate device.

[0018] These and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

## BRIEF DESCRIPTION OF THE DRAWINGS

### [0019]

Figures 1A to 1E are cross-sectional views, each illustrating a step of a fabrication method of a semiconductor substrate device according to Embodiment 1 of the present invention.

Figure 2 is a plan view of a first semiconductor substrate used for the semiconductor substrate device according to Embodiment 1 of the present invention.

Figures 3A to 3E are cross-sectional views, each illustrating a step of a fabrication method of a semiconductor substrate device according to Embodiment 2 of the present invention.

Figures 4A to 4D are cross-sectional views, each illustrating a step of a fabrication method of a semiconductor integrated circuit according to document 1.

Figures 5A to 5E are cross-sectional views, each illustrating a step of a fabrication method of a semiconductor device according to document 2.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

##### (Embodiment 1)

[0020] Hereinafter, a semiconductor substrate device and a fabrication method of the semiconductor substrate device according to Embodiment 1 of the present invention will be described in detail with reference to Figures 1A to 1E.

[0021] Figures 1A to 1E are cross-sectional views, each illustrating a step of the fabrication method of the semiconductor substrate device according to Embodiment 1 of the present invention.

(1) As shown in Figure 1A, a first semiconductor substrate 21 is prepared. A first silicon oxide film 22 having a thickness of about 20 nm is formed on a top surface of the first semiconductor substrate 21. The first semiconductor substrate 21 contains, for example, silicon.

(2) As shown in Figure 1B, a resist layer 23 patterned to have a plurality of square areas at equal intervals is formed on the first silicon oxide film 22 by using a photolithography technique. Then, using the resist layer 23 as a mask, a region in the first silicon oxide film 22 corresponding to the opening of the resist layer 23 is removed by anisotropic etching or isotropic etching. Subsequently, using the resist layer 23 as a mask again, a region in the first semiconductor substrate 21 corresponding to the opening of the resist layer 23 is removed by dry etching. The first semiconductor substrate 21 is etched to a depth of about 1.5  $\mu\text{m}$  from a top surface of the semiconductor substrate 21 and the obtained etched surface is substantially flat.

(3) As shown in Figure 1C, the resist layer 23 and

remaining portions of the first silicon oxide film 22 are removed. As a result, as shown in Figure 2, the first semiconductor substrate 21 having a plurality of convex portions 21b in a substantially flat concave portion 21a is obtained. The convex portions 21b have square cross sections and are positioned at equal intervals across the entire surface of the wafer. Thus, the semiconductor substrate 21 has a concave-convex surface.

(4) As shown in Figure 1D, a second semiconductor substrate 24 having an oxide film 25 on a surface thereof is prepared. The second semiconductor substrate 24 and the first semiconductor substrate 21 are brought together by an ELTRAN (Epitaxial Layer Transfer) method so that the oxide film 25 and the concave-convex surface of the first semiconductor substrate 21 contact each other.

In an ELTRAN method, a thin-film Si layer is epitaxially grown on a first semiconductor substrate. The first semiconductor substrate and a second semiconductor substrate are brought together so that the two substrates sandwich the thin-film Si layer. Then, heat treatment is performed to improve adherence strength between the two substrates.

For bringing the first semiconductor substrate 21 and the second semiconductor substrate 24 together, other methods, such as a UNIBOND method, may be used.

In a UNIBOND method, hydrogen ions are implanted to a first semiconductor substrate. A second semiconductor substrate has a silicon oxide film. By utilizing a brittle fracture property of hydrogenion-implanted regions, the first semiconductor substrate and the second semiconductor substrate are brought together so that the two substrates sandwich the silicon oxide film. Then, heat treatment is performed.

(5) As shown in Figure 1E, the second semiconductor substrate 24 is polished from the opposite surface to the surface adhering to the first semiconductor substrate 21 to form a thin film. Thus, an SOI substrate device (i.e., the semiconductor substrate device) having a desired thickness is obtained.

[0022] In the semiconductor substrate device fabricated by steps (1) to (5) described above, a cavity 21c is formed in the first semiconductor substrate 21 before forming circuit elements (not shown). Therefore, it is not required to form the cavity 21c in the semiconductor substrate device after forming the circuit elements. Accordingly, damages to the circuit elements which may occur when forming cavities after the circuit elements are formed can be avoided, unlike in the methods of documents 1 and 2.

[0023] Furthermore, according to the present invention, it is not required to form openings which penetrate

through the semiconductor substrate from the surface of the semiconductor substrate device having the circuit elements thereon, unlike the semiconductor integrated circuit of document 2. Therefore, the semiconductor substrate device of the present invention can be preferably used for a high-frequency device which has a complicated arrangement.

[0024] Heat treatment performed for forming the circuit elements may cause an excessive thermal expansion of the cavity 21c in the first semiconductor substrate 21 in the semiconductor substrate device of the present invention. Even in such a case, the thermal stress is uniform across the semiconductor substrate device because the convex portions 21b are equally spaced in the first semiconductor substrate 21. Therefore, defects in the semiconductor substrate device, such as cracks, caused by uneven stress can be avoided.

[0025] In the first semiconductor substrate 21, the size of the convex portions 21b is preferably as small as possible, but is sufficiently large so as to provide a sufficient adherence strength between the first semiconductor substrate 21 and the second semiconductor substrate 24, for example.

(Embodiment 2)

[0026] Now, a semiconductor substrate device and a fabrication method of the semiconductor substrate device according to Embodiment 2 of the present invention will be described in detail with reference to Figures 3A to 3E.

[0027] Figures 3A to 3E are cross-sectional views, each illustrating a step of the fabrication method of the semiconductor substrate device according to Embodiment 2 of the present invention.

(1) As shown in Figure 3A, a first semiconductor substrate 31 is prepared by forming a first silicon oxide film 22 having a thickness of about 20 nm on a top surface of the first semiconductor substrate 31. The first semiconductor substrate 31 contains, for example, silicon.

(2) As shown in Figure 3B, a resist layer 23 patterned to have a plurality of square areas at equal intervals is formed on the first silicon oxide film 22 by using a photolithography technique. Then, using the resist layer 23 as a mask, a region in the first silicon oxide film 22 corresponding to the opening of the resist layer 23 is removed by anisotropic etching or isotropic etching. Subsequently, using the resist layer 23 as a mask again, a region in the first semiconductor substrate 31 corresponding to the opening of the resist layer 23 is removed. By using an anisotropic etchant, such as KOH, the first semiconductor substrate 31 is etched to a depth of about 1.5  $\mu$ m so that the width of a concave portion

31a formed narrows as the depth of the concave portion 31a increases (shown as triangular shaped concave portions in Figure 3B, for example).

5 (3) As shown in Figure 3C, the resist layer 23 and remaining portions of the first silicon oxide film 22 are removed. As a result, as shown in Figure 2, the first semiconductor substrate 31 having a plurality of convex portions 31b in the concave portion 31a is obtained. The convex portions 31b have square cross sections and are positioned at equal intervals across the entire surface of the wafer. Thus, the semiconductor substrate 31 has a concave-convex surface.

10 15 (4) As shown in Figure 3D, a second semiconductor substrate 24 having an oxide film 25 on a surface is prepared. The second semiconductor substrate 24 and the first semiconductor substrate 31 are brought together by an ELTRAN (Epitaxial Layer Transfer) method so that the oxide film 25 and the concave-convex surface of the first semiconductor substrate 31 contact each other.

20 25 For bringing the first semiconductor substrate 31 and the second semiconductor substrate 24 together, other methods, such as a UNIBOND method may be used.

30 35 (5) As shown in Figure 3E, the second semiconductor substrate 24 is polished from the opposite surface to the surface adhering to the first semiconductor substrate 31 to form a thin film. Thus, an SOI substrate device (i.e., the semiconductor substrate device) having a desired thickness is obtained.

40 [0028] In the semiconductor substrate device fabricated by steps (1) to (5) described above, a cavity 31c is formed in the first semiconductor substrate 31 before forming circuit elements (not shown). Therefore, it is not required to form the cavity 31c in the semiconductor substrate device after forming the circuit elements. Accordingly, damages to circuit elements which may occur when forming cavities after the circuit elements are formed can be avoided, unlike in the methods of documents 1 and 2.

45 [0029] Furthermore, according to the present invention, it is not required to form openings which penetrate through the semiconductor substrate from the surface of the semiconductor substrate device having the circuit elements thereon, unlike the semiconductor integrated circuit of document 2. Therefore, the semiconductor substrate device of the present invention can be preferably used for a high-frequency device which has a complicated arrangement.

50 55 [0030] Heat treatment performed for forming the circuit elements may cause an excessive thermal expansion of the cavity 31c in the first semiconductor substrate 31 in the semiconductor substrate device of the present

Invention. Even in such a case, the thermal stress is uniform across the semiconductor substrate device because the convex portions 31b are equally spaced in the first semiconductor substrate 31. Therefore, defects in the semiconductor substrate device, such as cracks, caused by uneven stress can be avoided.

[0031] A semiconductor substrate device according to the present invention has a cavity, without any circuit elements. When the circuit elements are provided on the semiconductor substrate device, the cavity in the semiconductor substrate device serves as a low dielectric constant portion, and thus parasitic capacitance generated between the substrate and the circuit elements, which may cause deterioration of high-frequency characteristics of a high-frequency device associated with the semiconductor substrate device, is reduced. Therefore, the semiconductor substrate device according to the present invention has good high-frequency characteristics and can be preferably used for the high-frequency device.

[0032] Various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be broadly construed.

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the first insulating film by using the resist layer as a mask, and performing anisotropic etching of the first semiconductor substrate by using the resist layer as a mask to form a concave-convex portion in a surface of the first semiconductor substrate to provide the first semiconductor substrate with the concave-convex surface; and removing the resist layer and the first insulating film, and then bringing the first semiconductor substrate and a second semiconductor substrate together so that the surface of the first semiconductor substrate and a second insulating film provided on a surface of the second semiconductor substrate contact each other.

4. A method according to claim 3, further comprising the step of thinning the second semiconductor substrate from a surface opposite to the surface thereof provided with the second insulating film after the step of bringing the first semiconductor substrate and the second semiconductor substrate together.
5. A method according to claim 3, wherein the anisotropic etching of the first semiconductor substrate is performed by using KOH.

## Claims

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## 1. A semiconductor substrate device, comprising:

a first semiconductor substrate including a concave-convex surface; and  
a second semiconductor substrate having an insulating film on a surface thereof,

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wherein the first semiconductor substrate and the second semiconductor substrate are brought together so that the surface of the first semiconductor substrate and the insulating film provided on the surface of the second semiconductor substrate contact each other to form a cavity in the semiconductor substrate device.

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## 2. A semiconductor substrate device according to claim 1, wherein the concave-convex surface of the first semiconductor substrate is defined by a plurality of convex portions formed at equal intervals.

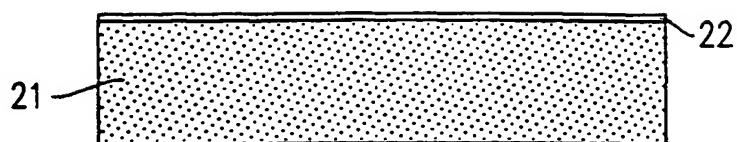
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## 3. A method for fabricating a semiconductor substrate device, comprising the steps of:

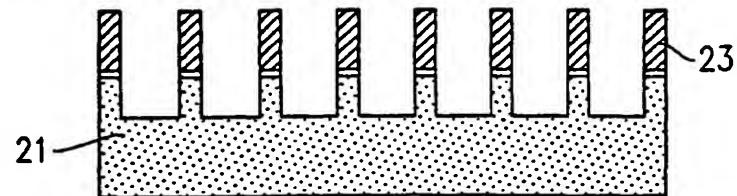
providing a resist layer having a predetermined pattern on a first insulating film on a first semiconductor substrate;  
performing isotropic or anisotropic etching of

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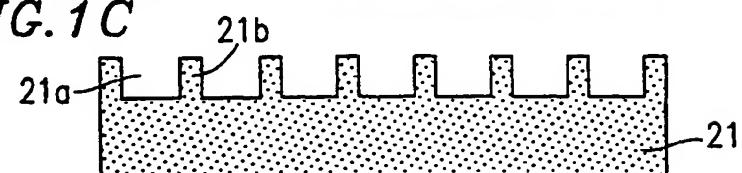
*FIG. 1A*



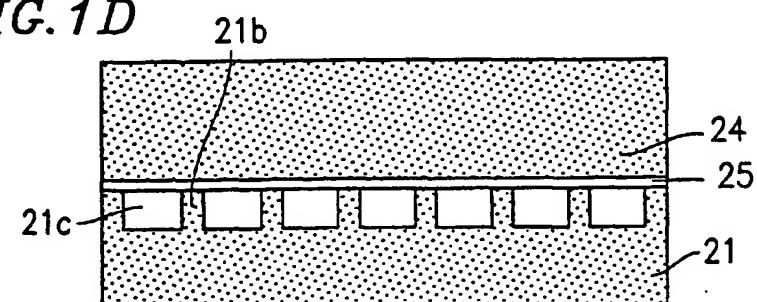
*FIG. 1B*



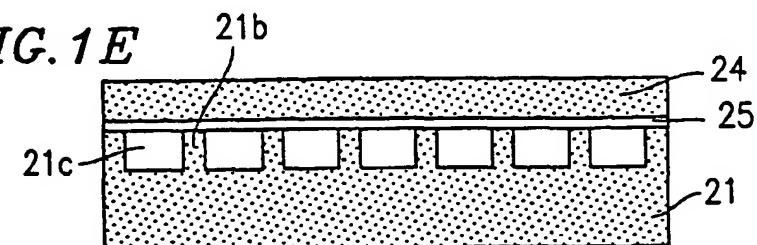
*FIG. 1C*



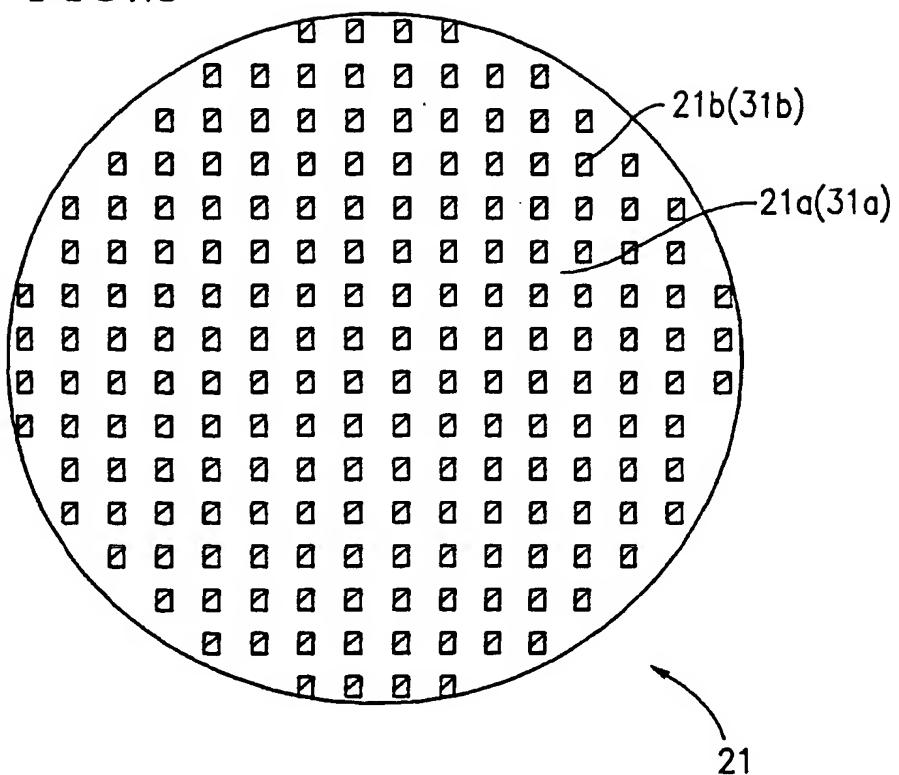
*FIG. 1D*



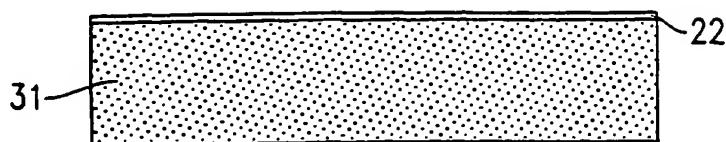
*FIG. 1E*



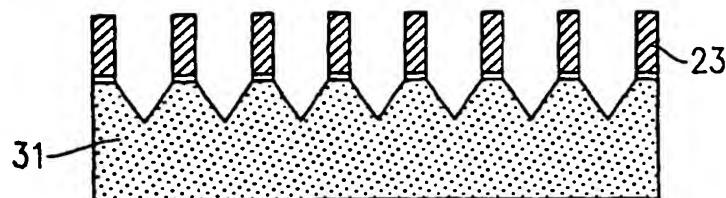
*FIG.2*



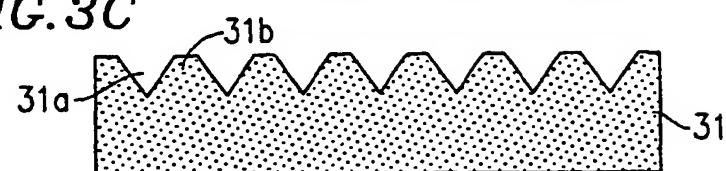
*FIG. 3A*



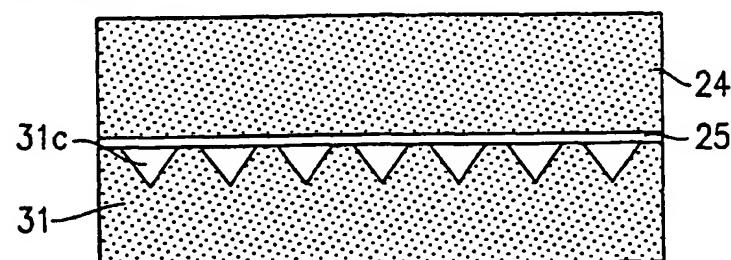
*FIG. 3B*



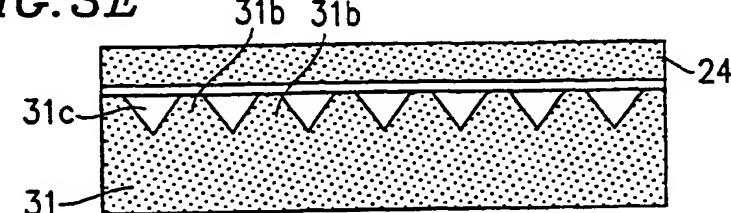
*FIG. 3C*



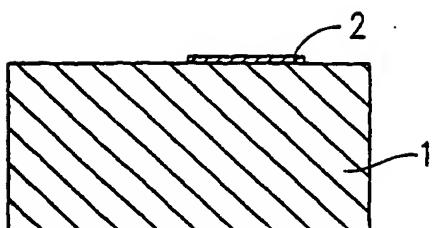
*FIG. 3D*



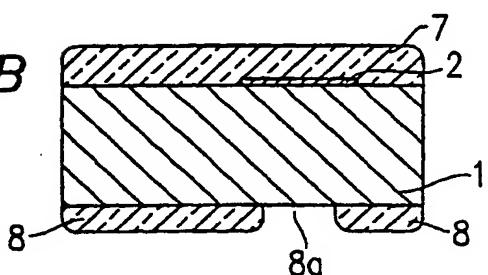
*FIG. 3E*



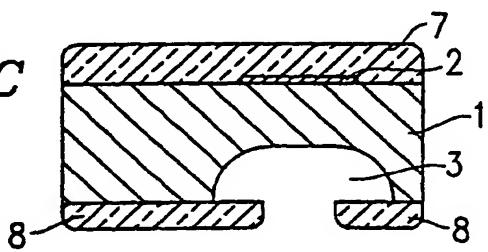
*FIG. 4A*



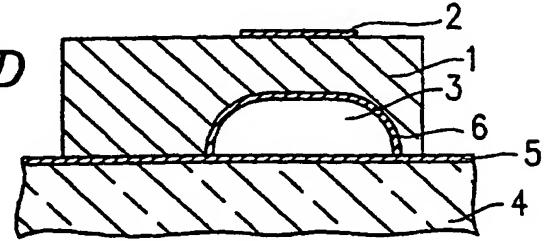
*FIG. 4B*



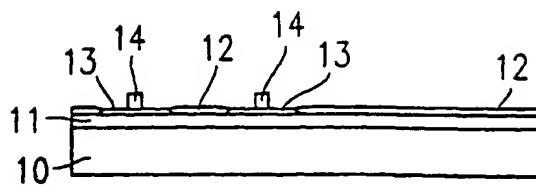
*FIG. 4C*



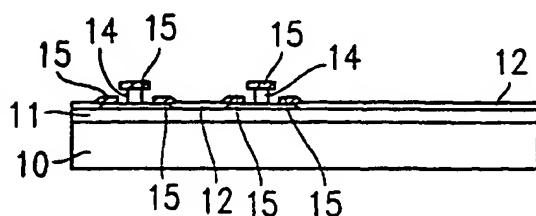
*FIG. 4D*



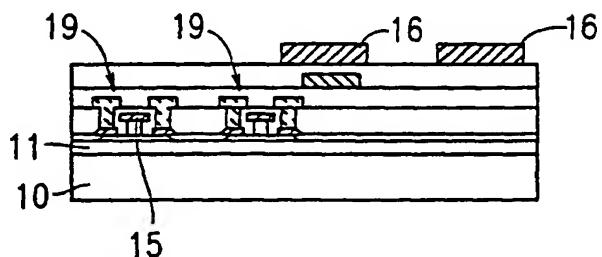
*FIG. 5A*



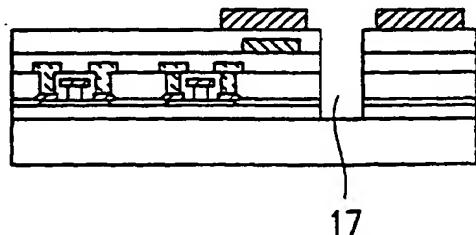
*FIG. 5B*



*FIG. 5C*



*FIG. 5D*



*FIG. 5E*

